High-Energy Neutrino Fluxes from Supermassive Dark Matter

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Supermassive dark matter

(Albuquerque, Chung, Hui, Kolb, Kuzmin, Riotto, Tkachev, …)

- Gravitationally produced towards end of inflation
- Never in thermal equilibrium, so present-day density is independent of interaction strength
- Most efficiently produced at very high masses (e.g. $\sim 10^{12}$ GeV in chaotic inflation)
- For a fairly large range of particle mass m_X and reheat temperature T_{RH}, can exist in sufficient quantities today

“Simpzillas”
(Strongly interacting, supermassive dark matter)

Assume simpzillas constitute entirety of dark matter density

?$_X$ ˜ 0.3 GeV / cm^3

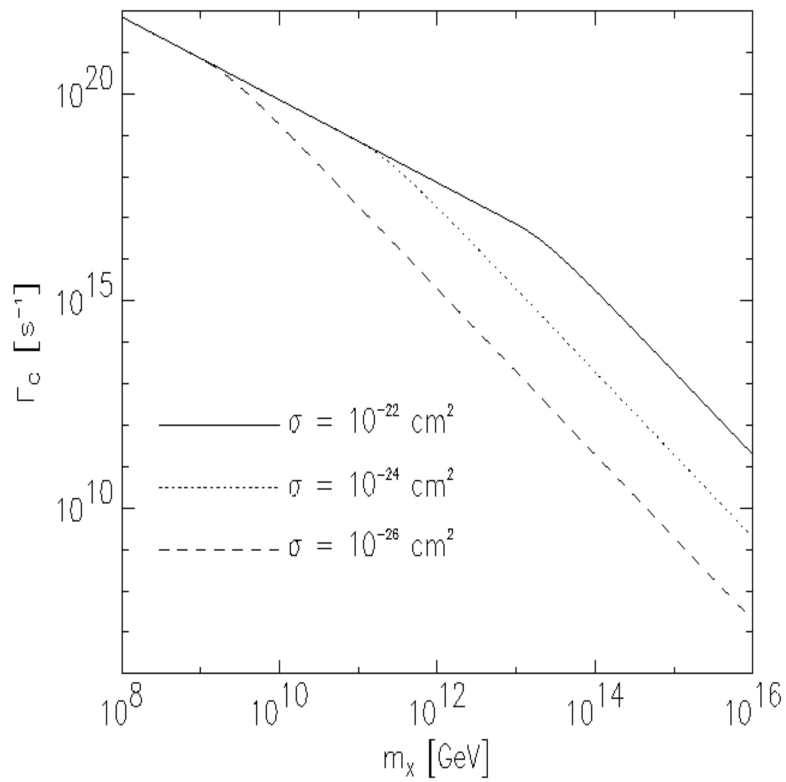
in Maxwell-Boltzmann velocity distribution

Assume simpzilla-baryon interaction cross section

s ~ *strong*

For annihilation cross section

s$_A$ = *weak*, equilibrium between capture and annihilation reached early in Sun’s history



Initial simpzilla neutrino flux

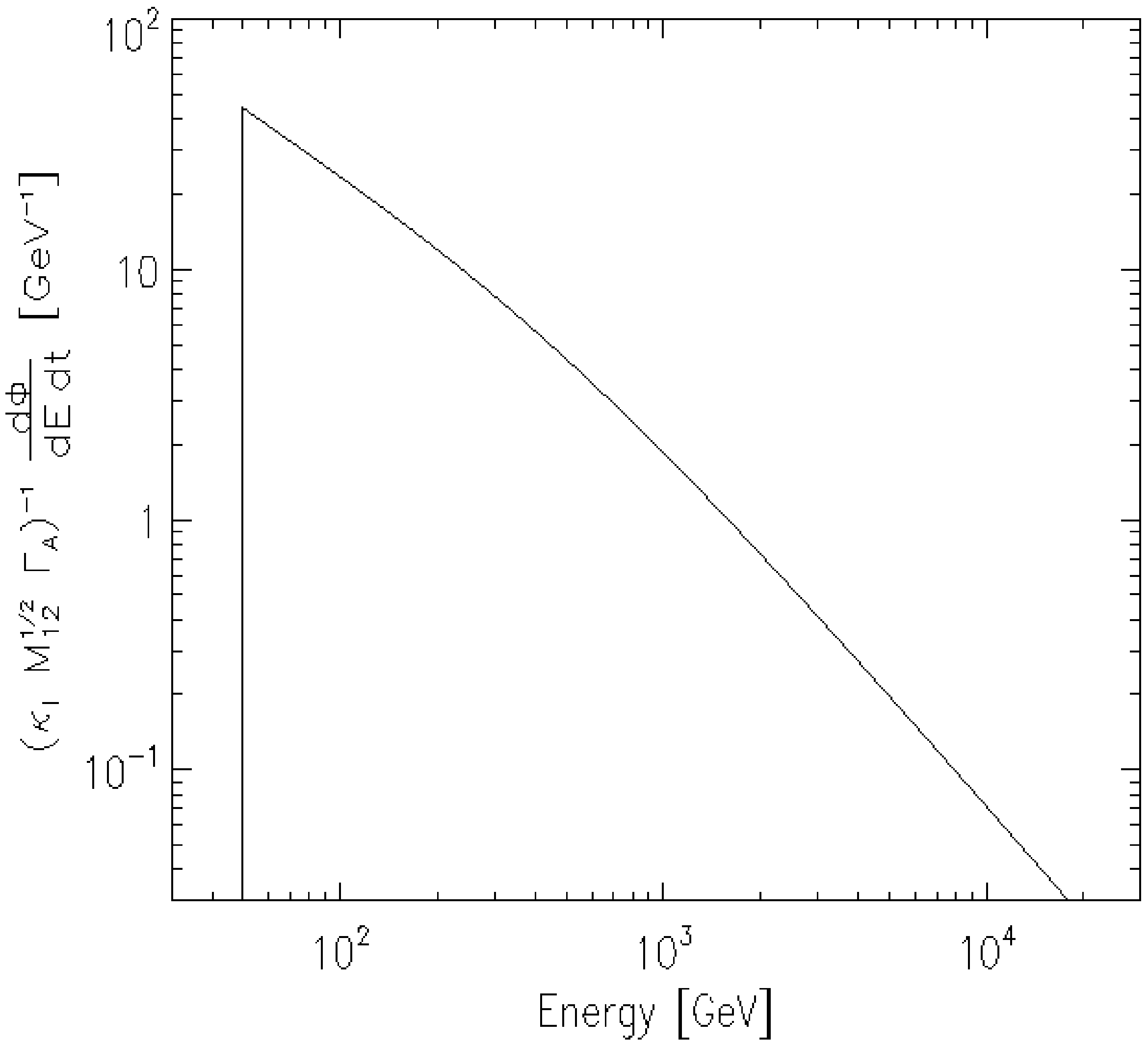
(Albuquerque, Hui, and Kolb 2001)

- Assume each simpzilla annihilation produces a quark or gluon pair which then fragment into hadronic jets.
- Hadrons containing light and charmed quarks will lose energy before decaying; consider only top hadron decays. (Neutrino flux from *B* mesons difficult to calculate.)
- Top hadron decay chain:

$t \rightarrow W\ b$	(100%)
$\quad \rightarrow e\ ?_e$	(10.5%)
$\quad \rightarrow \mu\ ?_\mu$	(10.5%)
$\quad \rightarrow t\ ?_t$	(10.5%)
$\qquad \rightarrow X\ ?_t$	(100%)
$\qquad\quad e\ ?_e$	(18%)
$\qquad\quad \mu\ ?_\mu$	(18%)

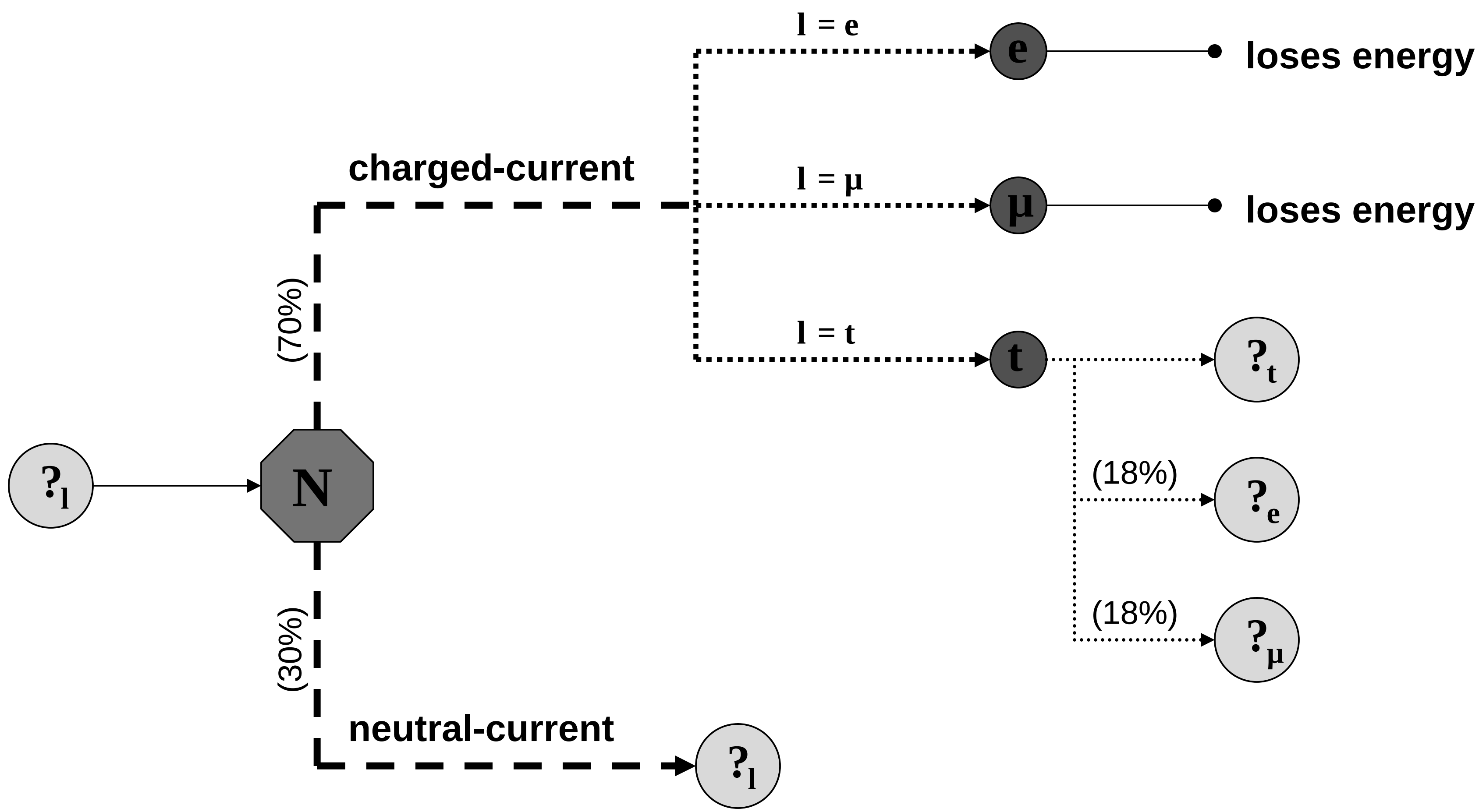
Initial simpzilla neutrino flux

(Albuquerque, Hui, and Kolb 2001)

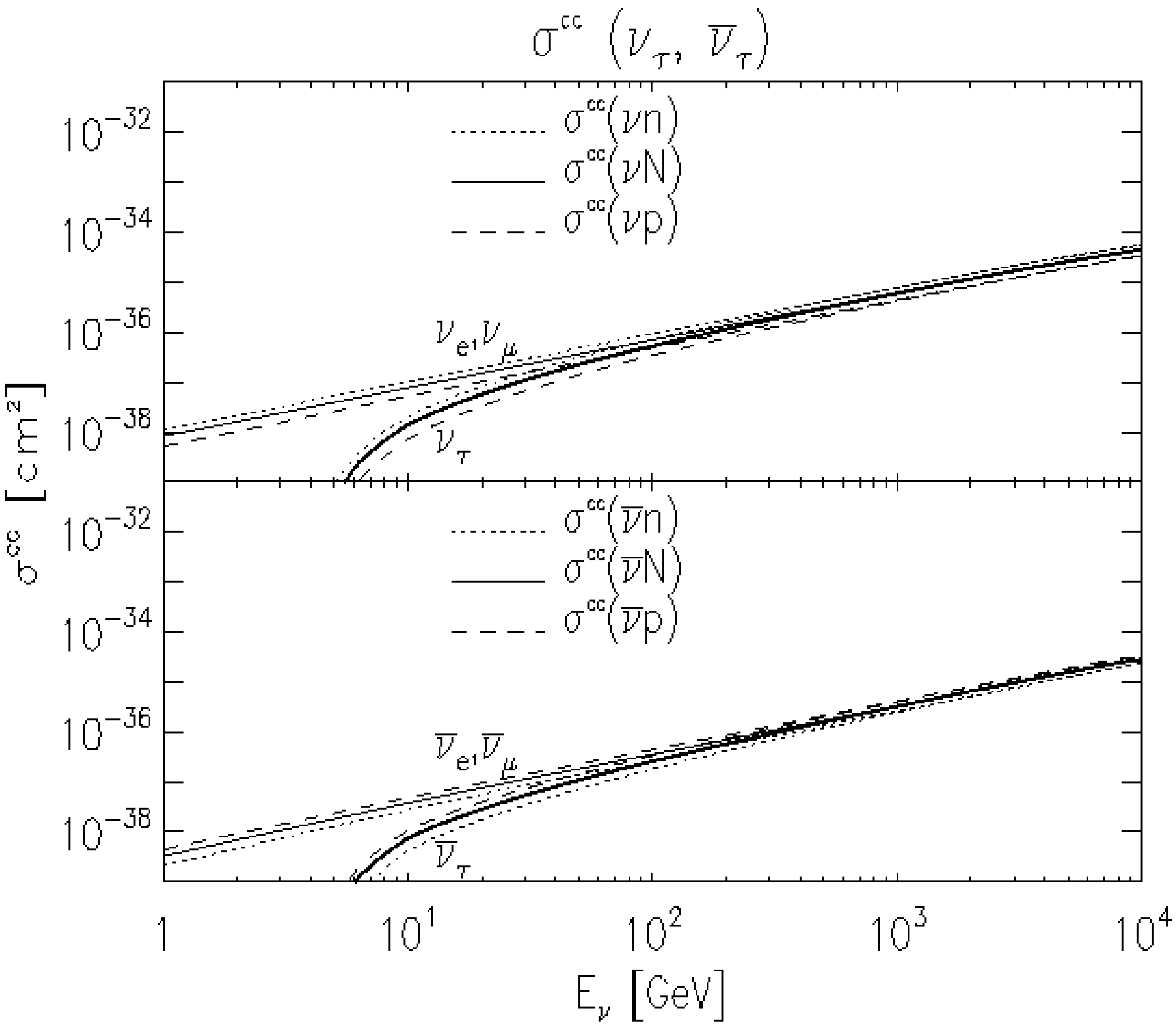


High-energy neutrino interactions in the Sun

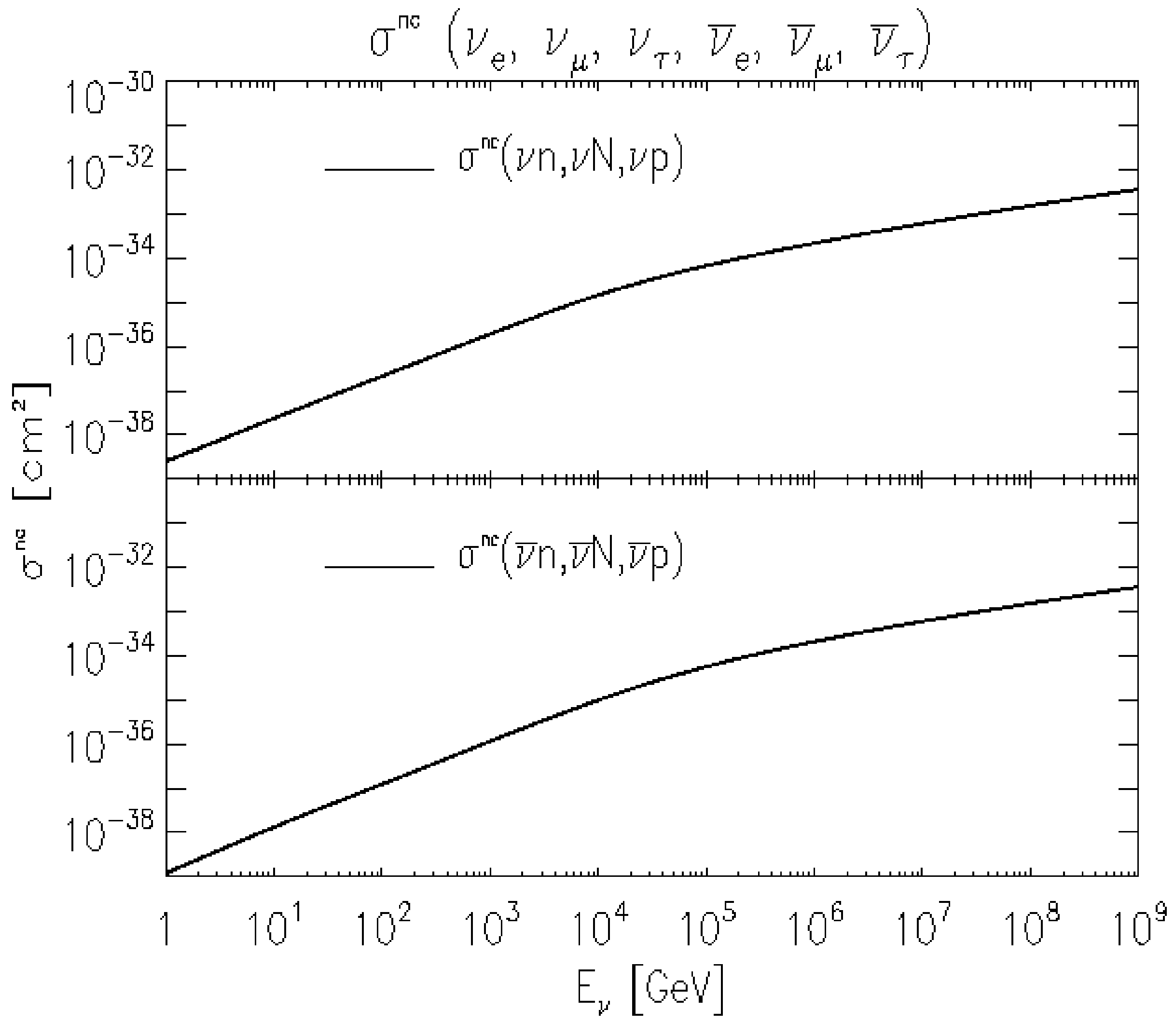
(Neglecting oscillations)



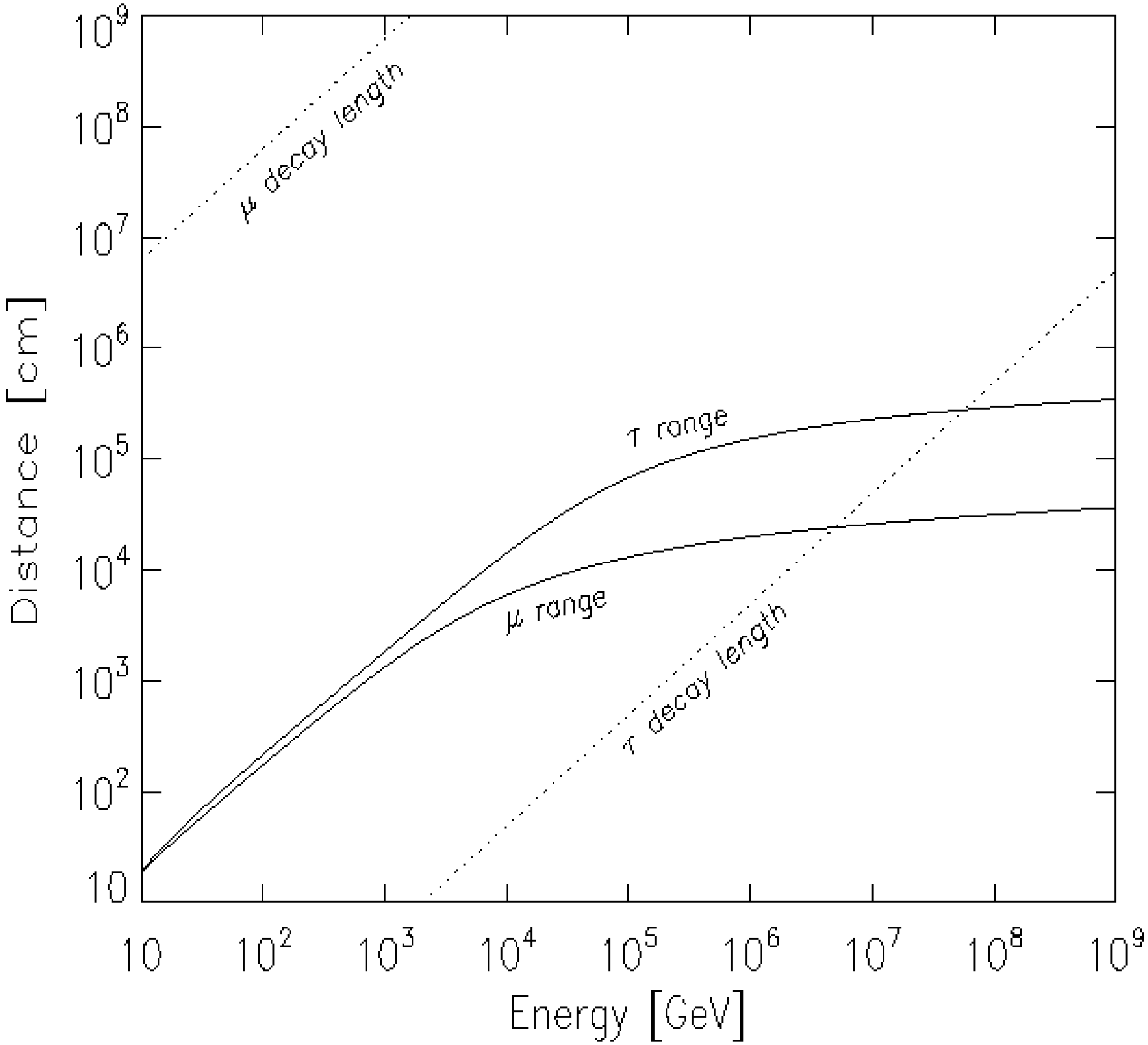
Charged-current cross sections
Calculated from CTEQ6-L parton distribution functions



Neutral-current cross sections
Calculated from CTEQ6-L parton distribution functions

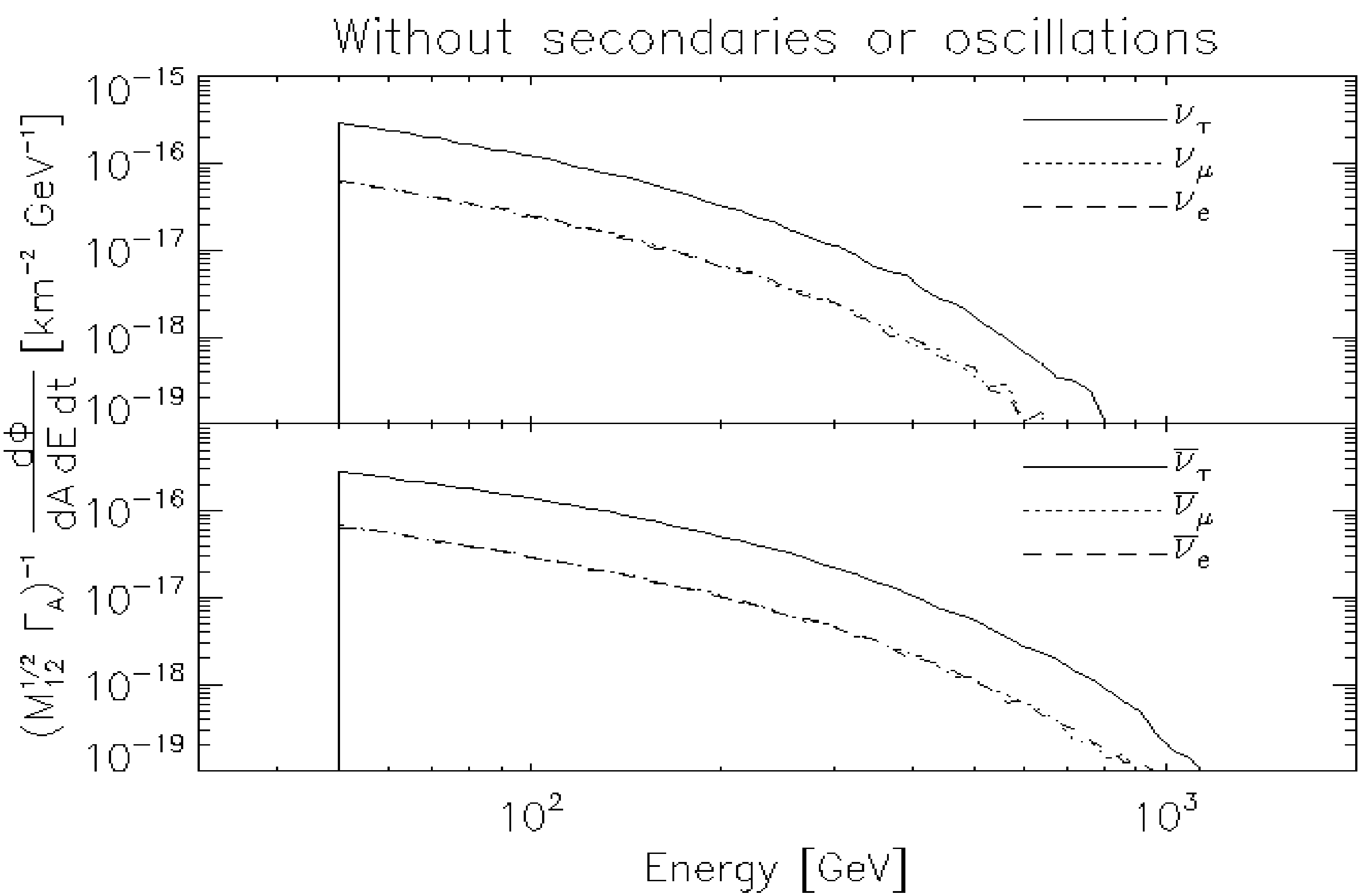


Charged lepton ranges and decay lengths
(In center of Sun)



Simpzilla neutrino flux at Earth

(Neglecting secondaries and oscillations)



Analytical approximation to emergent flux

Unscattered component (all flavors):

Cross sections are approximately linear functions of energy in this range, so have

$$\frac{d?_f}{dEdt} ? \frac{d?_0}{dEdt} e^{?E/E_k}$$

where E_k = energy such that mean # of interactions is 1 (**transparency energy)**

˜ 130 GeV ($?_e$, $?_\mu$), 160 GeV ($?_t$), 200 GeV ($\bar{?}_e$, $\bar{?}_\mu$), 230 GeV ($\bar{?}_t$)

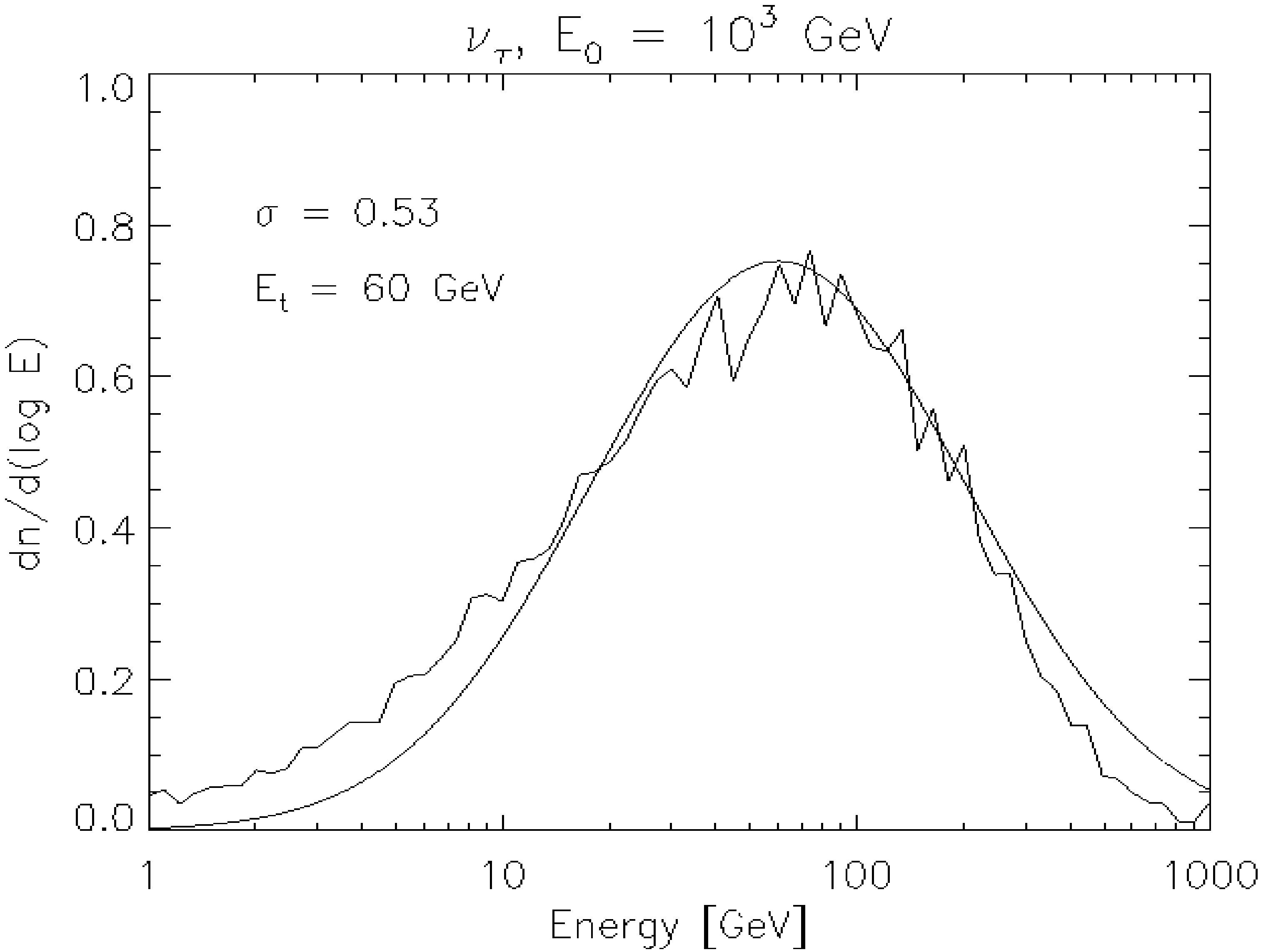
Scattered component (tau flavor only):

Find numerically that ~80% of tau neutrinos and antineutrinos emerge in **log-normal distribution:**

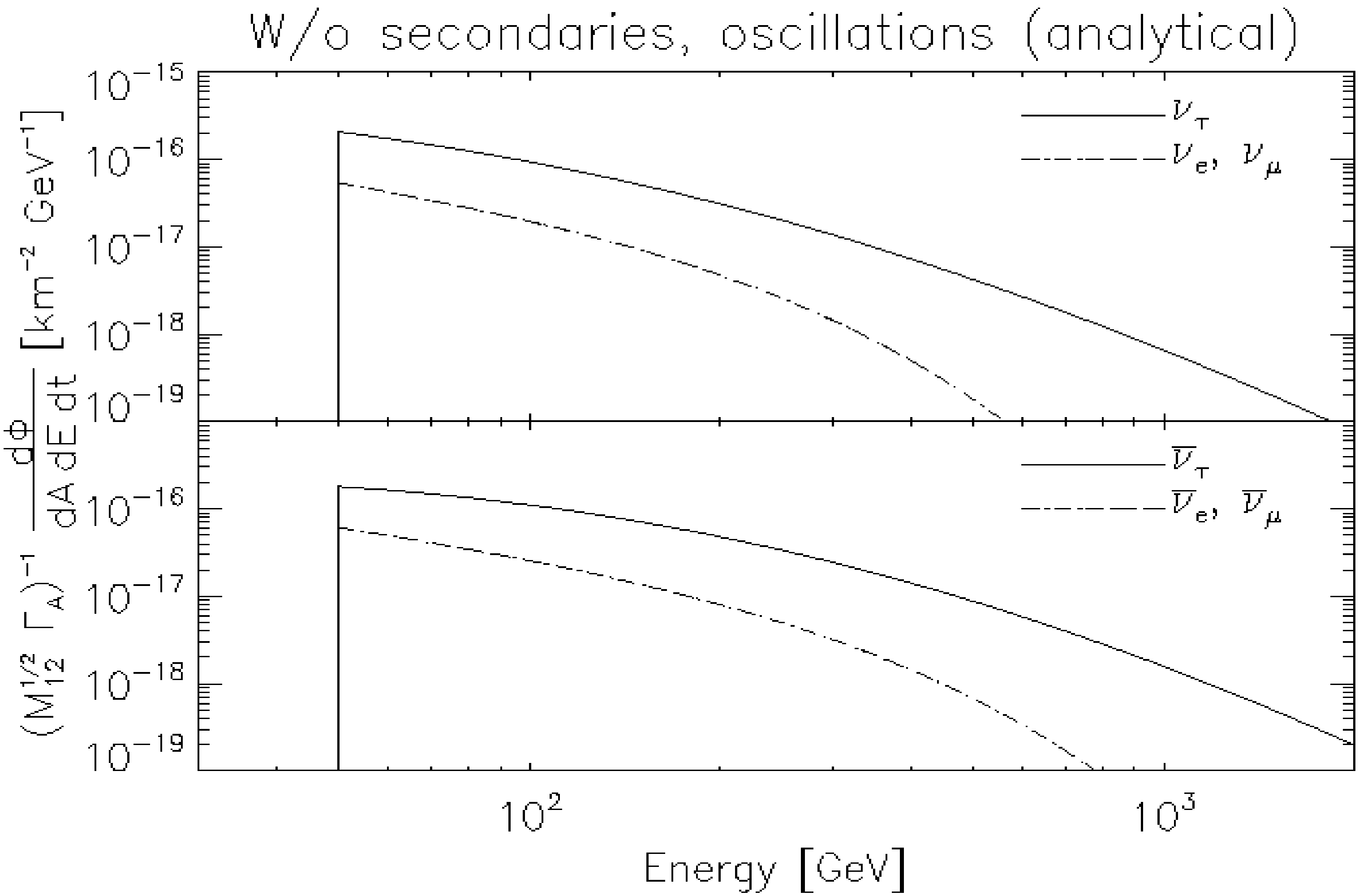
$$\frac{dn}{dE} ? \frac{1}{\sqrt{2?}\,(\ln 10)?E} \exp\left(? \frac{1}{2?^2} \log^2 \left(\frac{E}{E_t} \right) \right)$$

where {s, E_t} = {0.53, 60 GeV} ($?_t$), {0.49, 113 GeV} ($\bar{?}_t$)

Analytical approximation to emergent flux

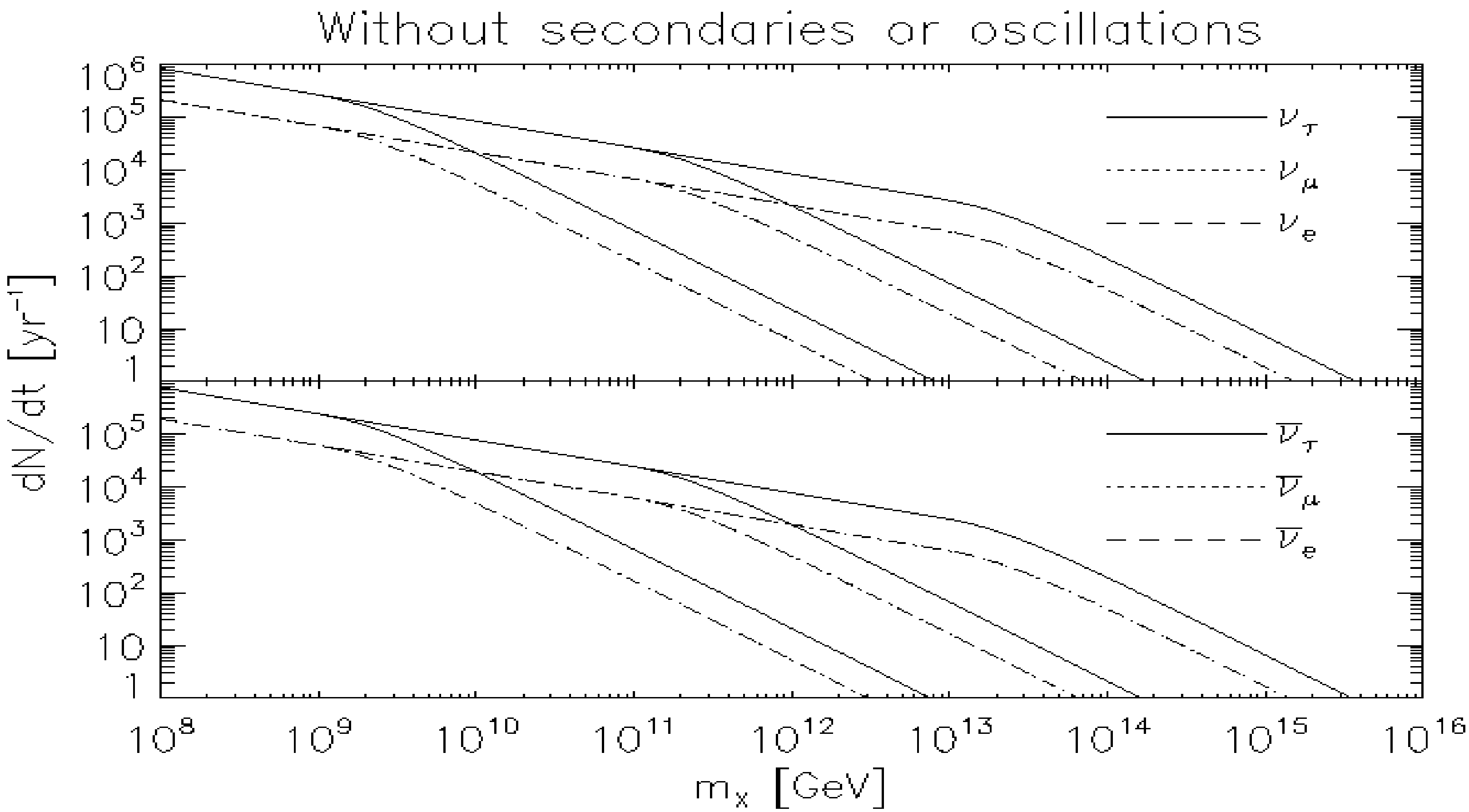


Analytical approximation to emergent flux, at Earth



Event rates in 1 km^3 ice detector

Assume detector has 10% energy resolution; can detect every charged-current interaction in its volume above 50 GeV; has angular resolution of 1º



Left to right: s = 10^{-26}, 10^{-24}, 10^{-22} cm^2

Neutrino oscillations

- Assume normal mass hierarchy:

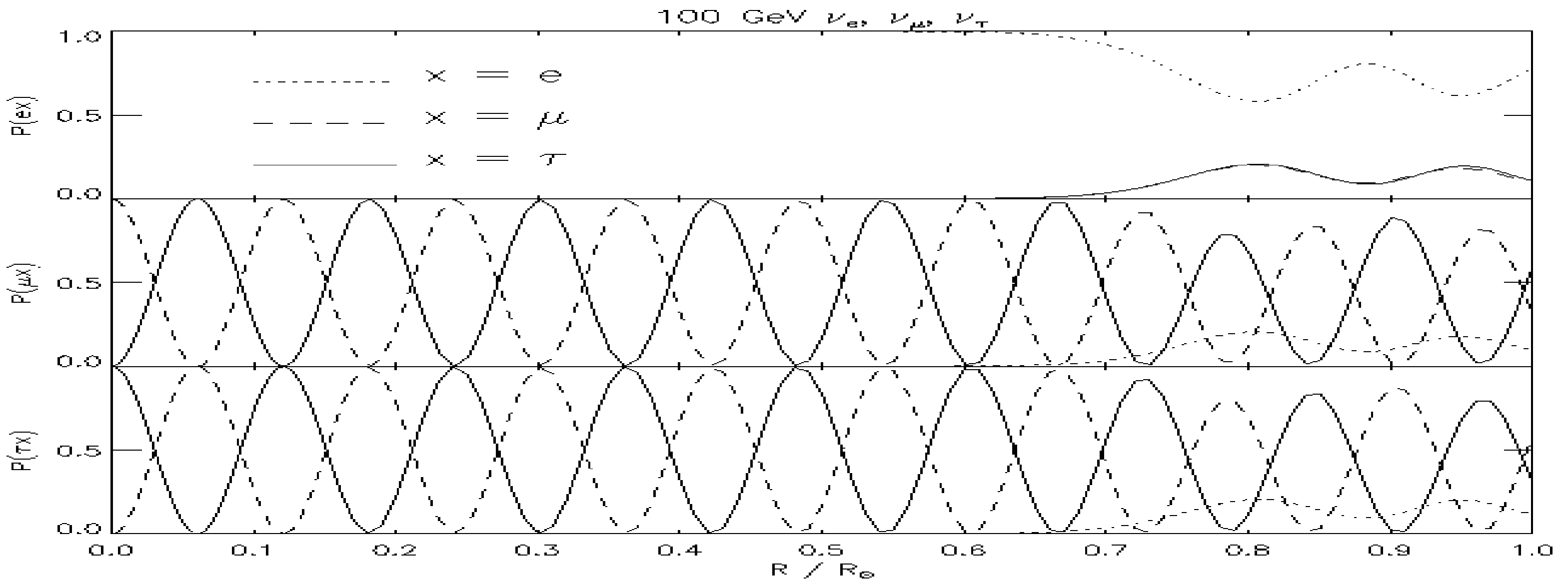
$$m_1 < m_2 < m_3$$

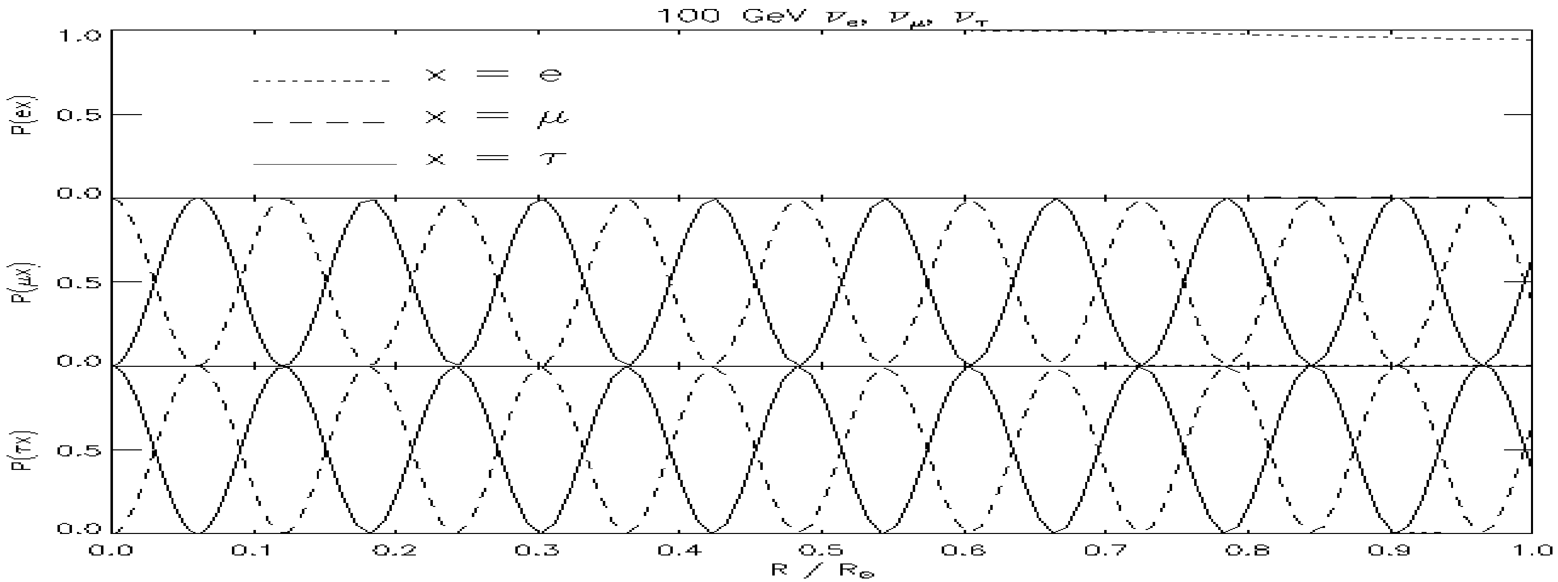
- Choose oscillation parameters from ranges suggested by SuperK & SNO (notation as in de Gouvêa 2001):

(SuperK)	(SNO, LMA)
$?m_{31}^2 = 3 \times 10^{-3}$ eV^2	$?m_{21}^2 = 2 \times 10^{-5}$ eV^2
$\sin^2 ? = 0.1$	$\sin^2 ? = 0.2$
$\sin^2 ? = 0.5$	

- Set CP violation parameter to 0
- Most significant uncertainties are sign of $?m_{31}^2$ and value of $?(U_{e3})$; this will modify emergent muon neutrino + antineutrino flux by a factor of ~2

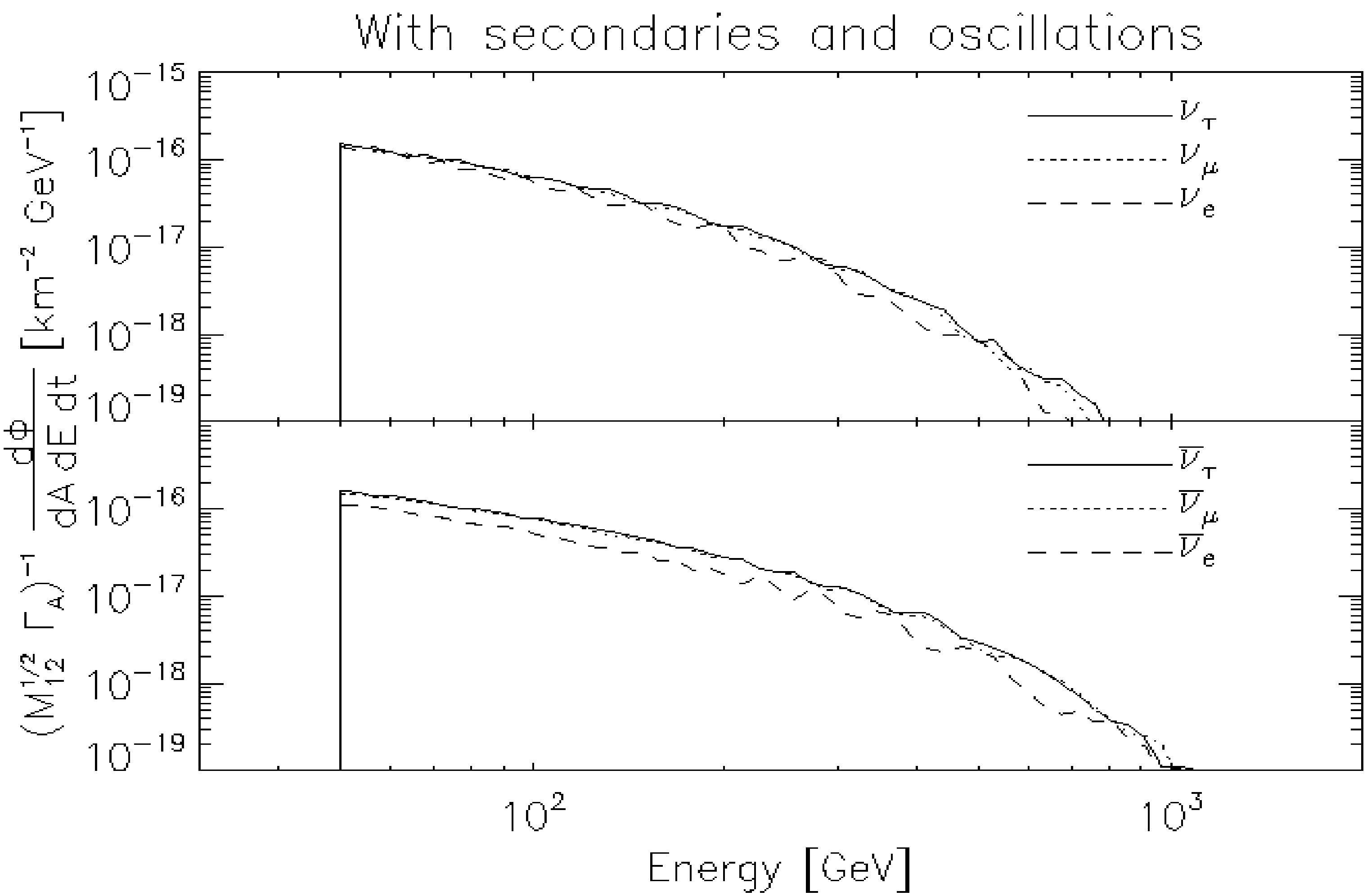
Neutrino oscillations



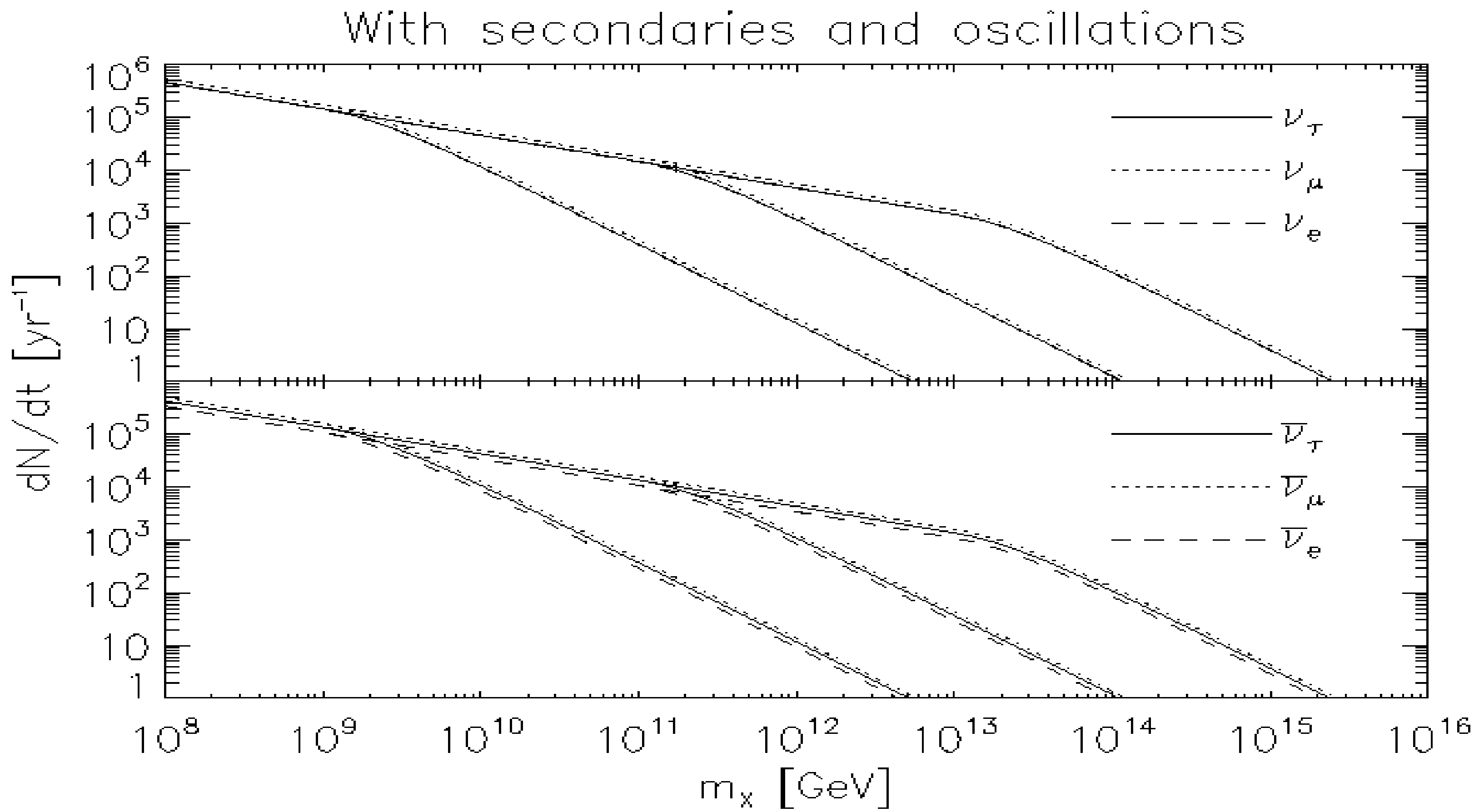


Simpzilla neutrino flux at Earth

(Including secondaries and oscillations)



Event rates in 1 km^3 ice detector

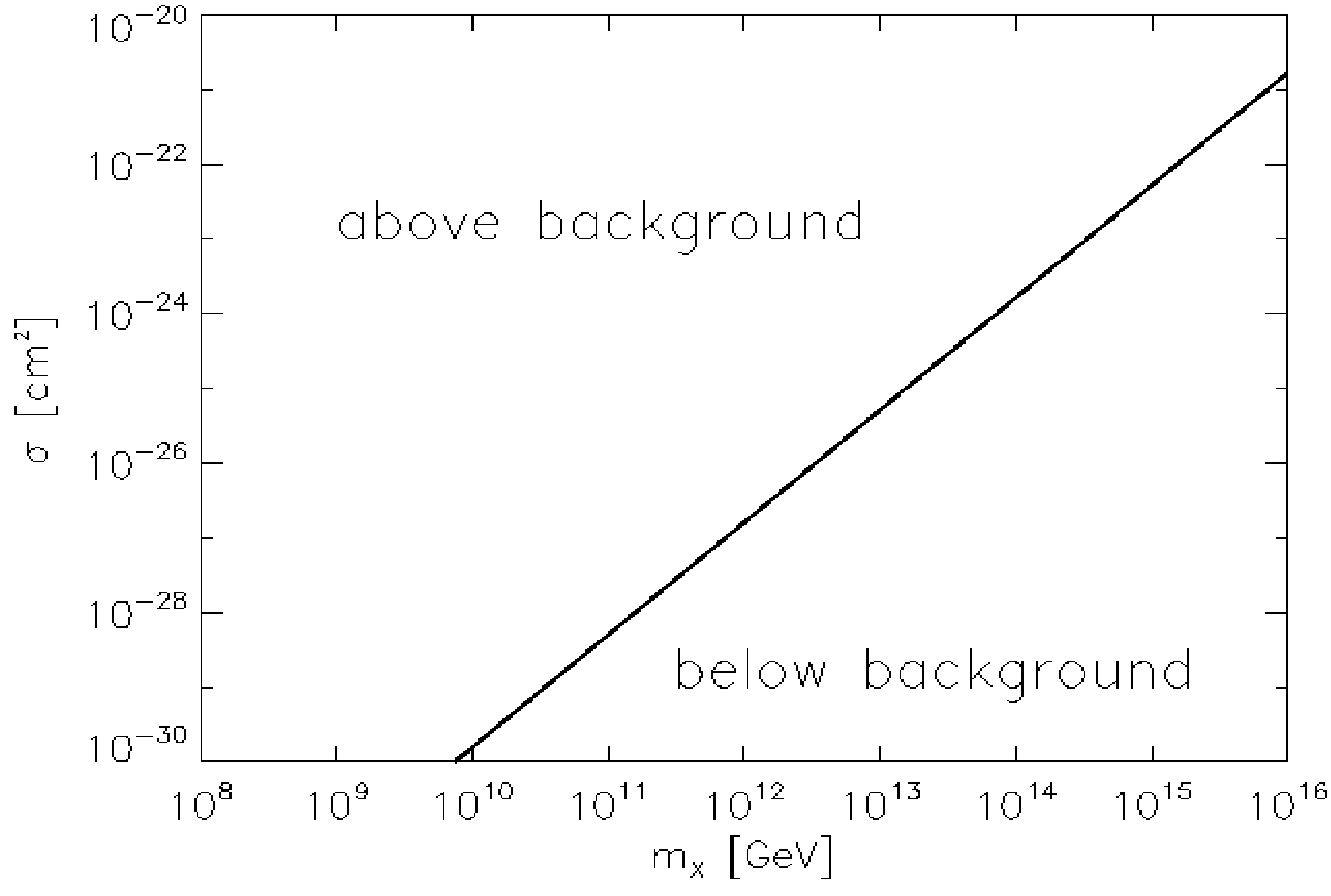


Left to right: s = 10^{-26}, 10^{-24}, 10^{-22} cm^2

Detectability of simpzilla neutrinos in a km^3 ice detector

Shown for each flavor

Background: ~2 (upcoming) ?$_\mu$ / yr



Summary

- If supermassive, strongly interacting particles (“simpzillas”) are a significant component of the dark matter, they will be captured by the Sun and produce a high-energy neutrino flux.
- In a km^3 ice detector, this signal will be well above background for a large region of simpzilla parameter space.
- Neutrino oscillations enhance the muon neutrino component of the flux at the Earth. This will also increase the signal’s detectability.
- Secondary neutrinos from tau decays do not substantially alter the signal, since much of the initial flux is below the transparency energy.
- If a high-energy neutrino signal from the Sun is detected, more work will be necessary to rule out other possible sources like thermal WIMPs.
- If no such signal is detected, then simpzillas in a broad range of mass and interaction cross section will be definitively excluded as a significant component of the dark matter.